How closely the physical cause of this discontinuity resembles that in the case of a carbon arc is still in doubt, though investigations bearing on this question are under way. With the iron arc there seems to be no sharply defined crater, for each electrode terminates in a viscous, incandescent globule of what seems to be magnetic oxide of iron, from which the discharge takes place. Thus we have to do, properly speaking, not with an arc between iron electrodes, but with one between electrodes of Fe_3O_4. Even when the arc is hissing strongly, the discharge seems to take place from only a small area on the surface of the globule. Moreover, a large increase in diameter of electrodes is accompanied by only a small increase in the value of the critical current, which varies between 0·8 ampere and 1·5 ampere over a wide range of values of length of arc and thickness of electrodes. On the other hand, I have found no positive evidence that the discontinuity is not due to the presence of oxygen around the anode. A test with an exploring electrode showed that the effect is confined mainly, if not entirely, to the anode. Given an arc burning on the quiet stage in the neighbourhood of the hissing point, the hissing can be precipitated by shortening the arc, just as in the case of the carbon arc.

After the current has been increased somewhat beyond the hissing point, the arc begins to rotate rapidly, so that on the anode a ring instead of a spot of light appears. This is accompanied by a high-pitched squeak or whistle, which, as the current is still further increased, degenerates into a sputter, and this in turn into a steady, strong hiss, the ring meanwhile having disappeared. At the beginning of the "whistling stage" the arc has a curious tendency to jump back into the quiet stage, so that for an instant the hissing ceases, the current falls abruptly, and the P.D. rises several volts. If one begins to diminish the current immediately after one of these abrupt changes, the quiet stage can sometimes be maintained steadily, even though the current is far greater than that at which hissing normally occurs. It is not impossible that slight irregularities in the supply E.M.F. may in certain circumstances serve to precipitate the change from the one stage to the other, even though the current be not that at which the change normally takes place.

In conclusion, the question may be raised whether Lecher's observation of the discontinuous nature of the arc discharge between iron electrodes was not made on the hissing stage alone, and whether, as with the carbon arc, the discharge may not be perfectly continuous when the current is made sufficiently small. It is planned to repeat Lecher's experiment, making tests on both the quiet and the hissing stages of the iron arc.

Middletown, Conn., August 9. W. G. Cady.

Volcanoes and Radio-activity.

In the *Popular Science Monthly* for June Major Dutton has an interesting article on the above subject, which was noticed in a recent issue of Nature. Having been occupied lately with the study of volcanoes in connection with a more general inquiry into the cause of earthquakes, it occurs to me to point out that Major Dutton has overlooked the recognised distribution of volcanoes about the sea coast, which seems completely to invalidate his theory. If radium, which the researches of the Hon. R. J. Strutt have shown to be so abundant in typical rocks of the earth's crust, such as granite, were an exciting cause of volcanic activity, we should expect to find an abundance of active volcanoes in the interior of continents, such as the United States, Europe, Asia, Africa, Australia, and Brazil, which is contrary to observation.

T. J. J. See.

Naval Observatory, Mare Island, California, August 10.

The Radio-activity of the Chemical Elements.

In connection with the emission, from the radio-active elements, of corpuscles with velocities below the critical velocity necessary for the ionisation of gases, it has occurred to me that such a form of radiation is possibly a fairly general property of the chemical elements. It is, I think, usually accepted that "γ" radiation always accompanies the projection of "β" particles, and the extreme penetration of the "γ" rays seems to be directly due to the very high velocity of the average "β" particle. As the efficiency of the "X" rays is due to the sudden negative acceleration of the unit electrical charges (*i.e.* the corpuscles) as they strike the anti-kathode, it appears quite possible that corpuscles, moving with comparatively low velocities, may yet be capable of causing a form of "γ" radiation of feeble penetrating power. The fact that the kathode stream, which can hardly penetrate the glass of the tube, is still able to set up very penetrating X radiation when given a sudden negative acceleration by impact with the platinum anti-kathode may perhaps be given as an instance in support of this idea. It seems probable that the photographic action of a beam of corpuscles (deviated away from the "γ" radiation by a magnetic field) may be chiefly due to a form of "γ" ray set up on contact with the plate itself. The several mysterious instances of the fogging of photographic plates left in certain conditions for considerable periods may be caused by a very feeble form of "γ" radiation set up by the impact of slow-moving corpuscles on the surrounding matter. Such evidence of these slow-moving corpuscles may be somewhat meagre and doubtful, but I think that, so far as the ordinary chemical elements are concerned, the emission of such corpuscles may be very much greater than the measured activities would lead us to suppose.

C. W. Raffety.

Streatham Common, August 25.

THE OXIDATION OF ATMOSPHERIC NITROGEN IN THE ELECTRIC ARC.

In the year 1775 Priestley published his "Experiments and Observations on Various Kinds of Air," in which he showed that when a series of sparks was passed through air, the air became acid. The experiment was carried out by means of a glass tube, having one end closed with wax through which a wire was fixed, the open end being placed over a solution of blue litmus. Sparks were passed between the solution and the wire, and in a short time the blue litmus turned red. He further noticed the important fact that the water gradually rose up towards the wire. The observations of Priestley were shortly afterwards substantiated by Cavendish, and in 1893 Lord Rayleigh, with better apparatus and appliances, repeated the experiments which ultimately led him to the discovery of argon. Priestley attributed the acidity to the formation of carbon dioxide, but Cavendish, on repeating the work, proved it to be due to the formation of nitric and nitrous acids.

After the successful experimental work of Lord Rayleigh, attention was turned towards the production of nitric acid from atmospheric nitrogen. But it was undoubtedly due to Sir William Crookes, who as president of the British Association in 1898 directed attention to the gradual depletion of the world's store of nitrogenous products, that the importance of the fixation of atmospheric nitrogen was recognised by the scientific and commercial world. At the present time about 1·5 million tons of Chili saltpetre are annually exported, but those who have studied the question consider that at this rate of exportation the Chilian beds will be, at the latest, depleted by 1940. But as the population of the world increases, the quantity of nitrogenous material required for fertilising purposes advances in equal ratio. Sir William Crookes pointed out in 1898 that the world's growth of wheat was about 163,000,000 acres, which at the average of 12·7 bushels per acre gave 2,070,000,000 bushels. "But thirty years hence the demand will be 3,260,000,000 bushels. . . . By increasing the present yield per acre to twenty bushels, we should with our present acreage secure a crop of the requisite amount." In order to give this increase, about 1·5 cwt. of nitrate of soda would be required to be applied annually to each acre, that is to say, 12,000,000 tons would be needed. As at present situated the world is not in a position to supply this vast amount of nitrogenous product. Since Crookes sounded this note of warning many attempts have been made to oxidise atmospheric nitrogen on a commercial scale, but until within the last fifteen months no process based upon electrical oxidation has been an actual commercial success. It yet remains to see whether the process of Drs. Caro and Frank, which depends upon the formation of calcium cyanamide, will be able to compete in the first place with natural nitrates and ammoniacal products, and, secondly, with the electric process of Birkeland and Eyde, which, as we will shortly show, appears to have solved the problem of the fixation of atmospheric nitrogen. Drs. Caro and Frank found that by passing nitrogen over heated barium carbide barium cyanide was produced thus,

$$BaC_2 + N_2 = Ba(CN)_2,$$

but that when calcium carbide was employed calcium cyanamide and not calcium cyanide is formed,

$$CaC_2 + N_2 = CaCN_2 + C.$$

When the cyanamide is heated with water under pressure it is decomposed with formation of ammonia and calcium carbonate,

$$CaCN_2 + 3H_2O = CaCO_3 + 2NH_3.$$

This process is stated to take place slowly when the cyanamide is distributed on the soil. Although the manufacturers state that cyanamide is stable and does not deteriorate on keeping, some at least of the users say it is unstable and deteriorates considerably as a fertiliser when kept.

An electrical process—that of Bradley and Lovejoy—which was almost a success, was worked for about eighteen months at Niagara. They employed a continuous current with a potential of 10,000 volts. As it is very difficult to keep steady discharges at this high voltage, a slowly rotating framework with projecting electrodes was employed. As it rotated, the electrodes, which were of platinum, approached other projecting electrodes; discharges were thus provoked, but immediately interrupted. In an apparatus of only 5 kilowatts as many as 414,000 arcs were produced per minute. The working of such an apparatus on a technical scale was, as might be supposed, of great difficulty, and although considerable quantities of nitric acid were produced per kilowatt year, it did not prove commercially successful.

In May, 1905, a factory was started at Notodden, in Norway, for the manufacture of calcium nitrate from air and limestone by means of the electric arc flames. A photograph of the factory as it is at present is shown in Fig. 1. In the Birkeland-Eyde process, which is worked at Notodden, a high-tension arc flame is produced between two pointed copper electrodes. The electrodes are attached to a high-tension alternator, and are placed equatorially between the poles of a powerful electromagnet, so that the terminals of the electrodes are in the middle of the magnetic field. An electric disc flame is thus produced which is shown diagrammatically in Fig. 2, and a photograph of the actual flame in Fig. 3. The photographed flame, which represented about 250 h.p., was produced between water-cooled electrodes made of copper tubing.

The working potential employed is 5000 volts, the current is an alternating one of 50 periods per second, and the distance of the terminals apart is about 8 mm. As already mentioned, the electrodes are copper tubes which are water-cooled, and are in the form of a narrow, elongated U; even with flames of 750 kilowatts at 5000 volts the same form of electrode can be employed. By cooling the electrodes, about 7·5 per cent. of the electric energy employed between the electrodes is removed as heat by the water.

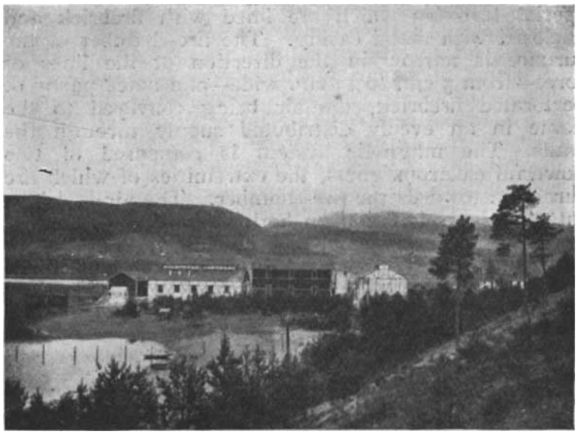

FIG. 1.—View of nitric acid factory at Notodden.

Prof. Birkeland explains the formation of the disc-flames in the following way:—"At the terminals of the closely adjacent electrodes, a short arc is formed, establishing an easily movable and ductile current conductor in a strong and extensive magnetic field, *i.e.* from 4000 to 5000 lines of force per sq. cm. in the centre. The arc then moves in a direction perpendicular to the lines of force, at first with an enormous velocity which subsequently diminishes; and the extremities of the arc retire from the terminals of the electrodes. As the length of the arc increases, its electrical resistance also increases, so that the tension is increased until it becomes sufficient to create a new arc at the points of the electrodes. The resistance of this short arc is very small, the tension of the electrodes therefore sinks suddenly, with the consequence that the outer long arc is extinguished. . . . In an alternating current all the arcs with a positive direction of current run one way, while all with a negative direction run the opposite way (see Fig. 2), presupposing the magnetising being effected by direct currents. In this manner a complete luminous circular disc is presented to the eye."

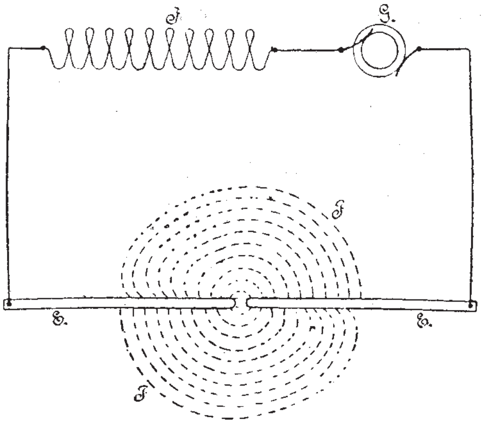

FIG. 2.—Diagram of electric arc flame.

It is interesting to note that the flame, considering its high electrical power, is not particularly luminous, as it is quite possible to look directly at it with the naked eye at a distance of about 1 yard, and it is not easy to snapshot it.

The alternating-current disc flame is enclosed in special furnaces which are lined with firebrick and enclosed with metal casing. The fire-chamber of the furnace is narrow in the direction of the lines of force—from 5 cm. to 15 cm. wide—and made partly of perforated firebrick, the air being conveyed to the flame in an evenly distributed supply through the walls. The magnetic system is composed of two powerful electromagnets, the extremities of which are turned in towards the fire-chamber. The air is driven into the central region on both sides of the flame by gentle pressure from a Roots blower; it must not be blown too rapidly, otherwise the flame is extinguished. Fig. 4 shows three of the furnaces, each furnace taking 500 kilowatts. The volume of air at present treated is 75,000 litres per minute, which after passing through the furnace contains about 1 per cent. of nitric oxide. The gases leave the furnace at a temperature of 600° to 700° C., and are first passed through a steam boiler, the steam from which is employed in the further manufacture of calcium nitrate. After passing from the boiler the temperature is about 200°, and by passage through a cooling arrangement the temperature is reduced to 50°.

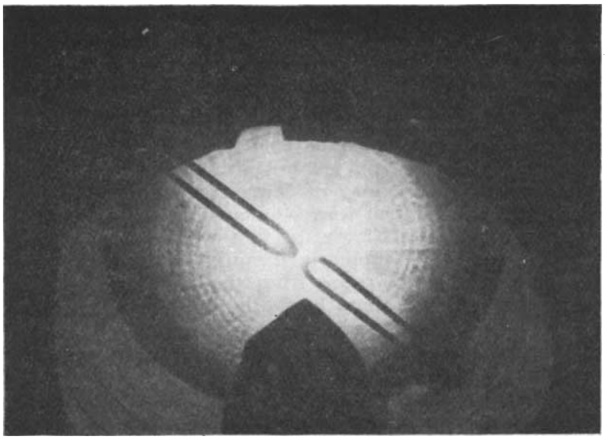

FIG. 3.—Photograph of electric arc flame, showing water-cooled electrodes.

The gases now pass into two large oxidising chambers with acid-proof lining, where the oxidation of the nitric oxide formed in the furnaces takes place with production of nitrogen peroxide. It is then conducted into an absorption system consisting of five towers, two being of granite and two of sandstone, filled with broken quartz over which water trickles, nitric acid thus being produced. The fifth tower is filled with broken bricks over which milk of lime trickles and which absorbs the now rarefied nitrous gases with formation of calcium nitrate and nitrite. In the plant at Notodden there are two such series of towers. The liquids from the fourth tower, which consist of 5 per cent. nitric acid, are raised to the top of the third tower by compressed air, those from the third to the second, and from the second to the first. The acid, on leaving the third tower, is of 15 per cent. strength, on leaving the second 25 per cent., and it leaves the fourth tower with a strength of 50 per cent.

Some of the acid produced is used to decompose the calcium nitrite obtained from the fifth tower and to convert unchanged lime into nitrate. The oxides of nitrogen produced by the decomposition of the nitrite are carried back to the system of towers. The solution resulting is run, together with the rest of the stored-up acid, into another series of granite tanks, where it reacts with limestone, thus producing neutral calcium nitrate. This solution is evaporated down until the temperature rises to 145°, answering to a concentration of 75 to 80 per cent. of calcium nitrate. The solution is then run into 200-litre drums, where it solidifies, and it appears on the market in this form. It is, however, found that for fertilising purposes it is better to use the basic nitrate owing to the extremely hygroscopic properties of the neutral salt. The ground-up basic nitrate can, as it is not hygroscopic, be readily scattered with a sowing machine.

Numerous manuring experiments have been made with calcium nitrate at different agricultural institutes. The results show that lime saltpetre is quite as good as Chili saltpetre, and on a sandy soil is even superior.

The yield of anhydrous nitric acid by the Birkeland-Eyde process is between 500 and 600 kilograms per kilowatt year. The cost of calcium nitrate containing 13·2 per cent. of nitrogen is about 4*l.* per ton, and the selling price about 8*l.* per ton. New works of 30,000 h.p. are now nearly completed, and it is hoped that the new factory will be very shortly in active operation. To an Englishman it is of interest to notice that *all* the pioneer work was carried out in this country. In this connection it should be remarked that even if the final stage—the application of the flame electric arc—had been tried in this country, it could not have been a commercial success. To be a commercial success it is *absolutely* essential that very cheap power should be at the disposal of the manufacturers. At present we have not this cheap power, and it is very improbable that we shall have it in the near future; unless, indeed, some engineer can show us how to harness the tides. But if we cannot manufacture nitric acid from the atmosphere there is a problem, probably a very difficult problem, the elucidation of which would be of almost untold value, and that is the fixation or utilisation of the nitrogen in sewage, which at present is almost entirely thrown with happy abandonment into the sea. As a consequence, the mouths of rivers are polluted, fish are destroyed, and, what is perhaps more serious, disease is often disseminated.

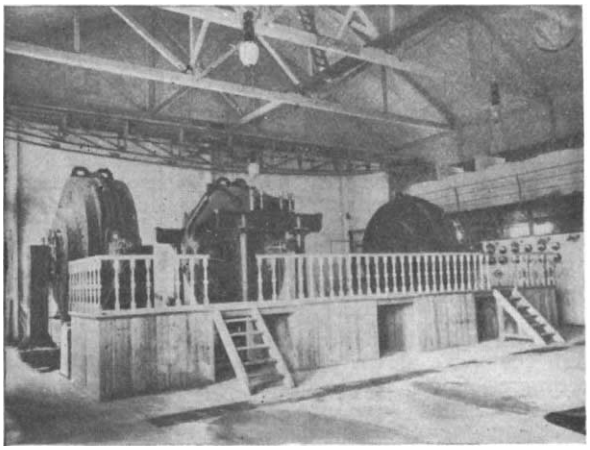

FIG. 4.—Photograph of three 500-kilowatt furnaces at Notodden.

F. MOLLWO PERKIN.